(12) UK Patent (19) GB (11) 2 355 538 (13) B

(45) Date of publication: 27.08.2003

(54) Title of the invention: Device and method for measurement of resistivity outside of a wellpipe

(51) Int Cl^7: **G01V 3/30**

(21) Application No: **0100784.8**

(22) Date of Filing: **17.06.1999**

(30) Priority Data:
(31) **19982827** (32) **18.06.1998** (33) **NO**

(86) International Application Data:
PCT/NO1999/000199 En 17.06.1999

(87) International Publication Data:
WO2000/000850 En 06.01.2000

(43) Date A Publication: **25.04.2001**

(52) UK CL (Edition V):
G1N NCLE N19B2A

(56) Documents Cited:
WO 1998/012417 A1 **US 5303773 A**
US 5233304 A

(58) Field of Search:
As for published application 2355538 A *viz:*
INT CL^6 **G01V**
Other:
updated as appropriate

(72) Inventor(s):
Fan-Nian Kong
Harald Westerdahl
Terje Eidesmo
Svein Ellingsrud

(73) Proprietor(s):
Den Norske Stats Oljeselskap a.s.
(Incorporated in Norway)
N-4035 Stavanger, Norway

Norges Geotekniske Institutt
(Incorporated in Norway)
Pb. 3930 Ulleval Hageby, 0806 Oslo, Norway

(74) Agent and/or Address for Service:
Kilburn & Strode
20 Red Lion Street, LONDON, WC1R 4PJ, United Kingdom

23 55538

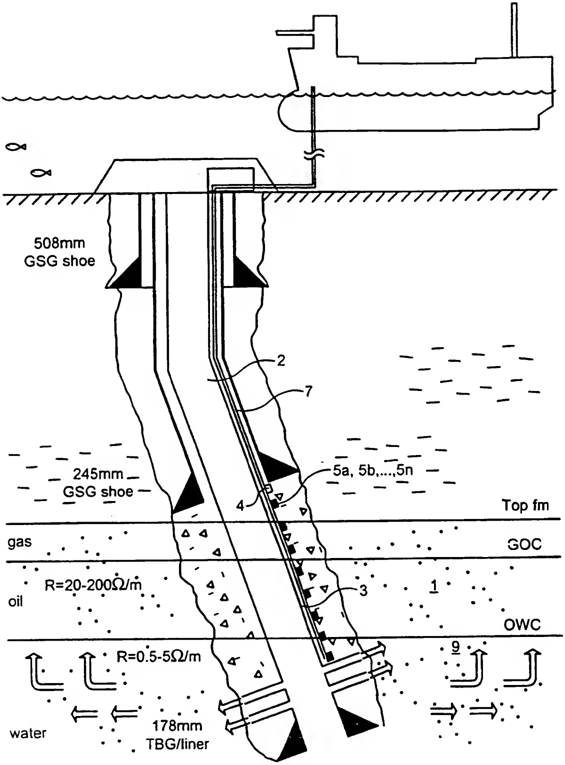


FIG. 1

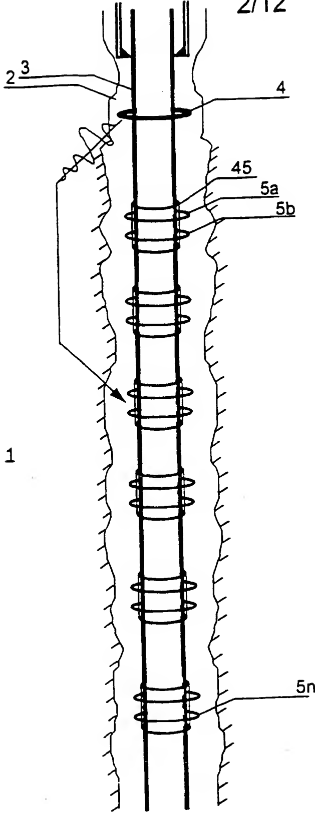


Fig. 2a

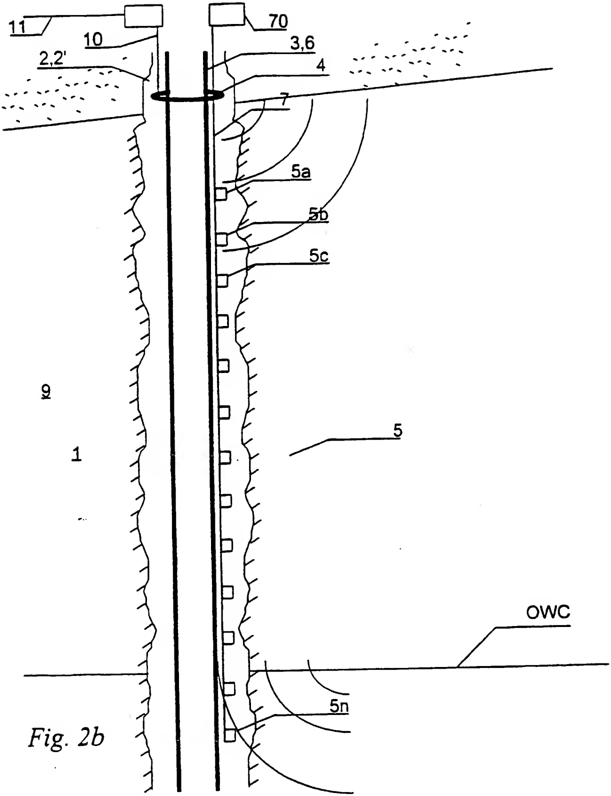


Fig. 2b

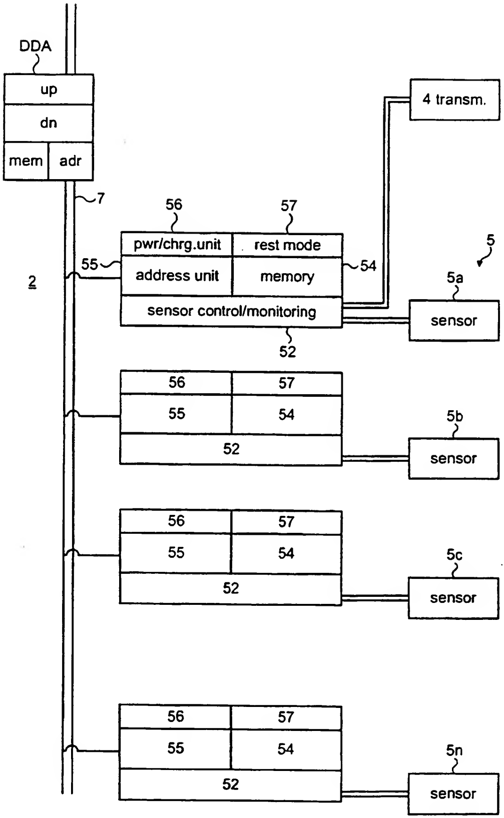

DDA
up
dn
mem
adr
7
2
56
57
pwr/chrg.unit
rest mode
55
address unit
memory
54
sensor control/monitoring
52
4 transm.
5
5a
sensor
56
57
55
54
52
5b
sensor
56
57
55
54
52
5c
sensor
56
57
55
54
52
5n
sensor

FIG. 3

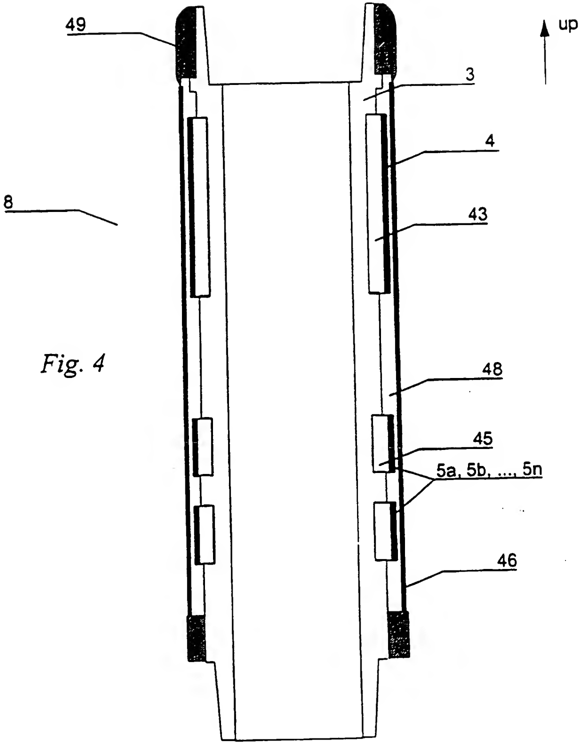
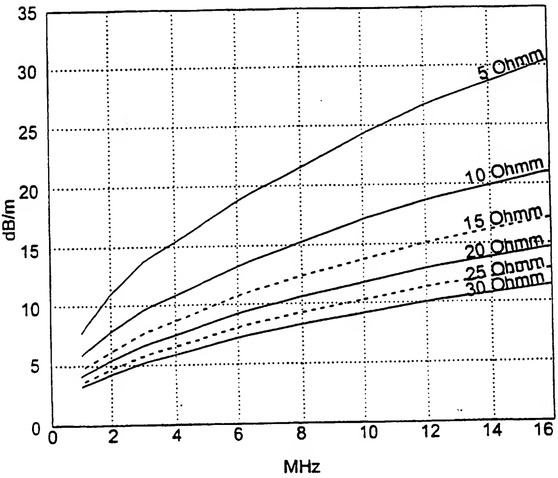


Fig. 4

Fig. 5


35
30
25
20
15
10
5
0
dB/m
0
2
4
6
8
10
12
14
16
MHz
5 Ohmm
10 Ohmm
15 Ohmm
20 Ohmm
25 Ohmm
30 Ohmm

7/12

Fig. 6

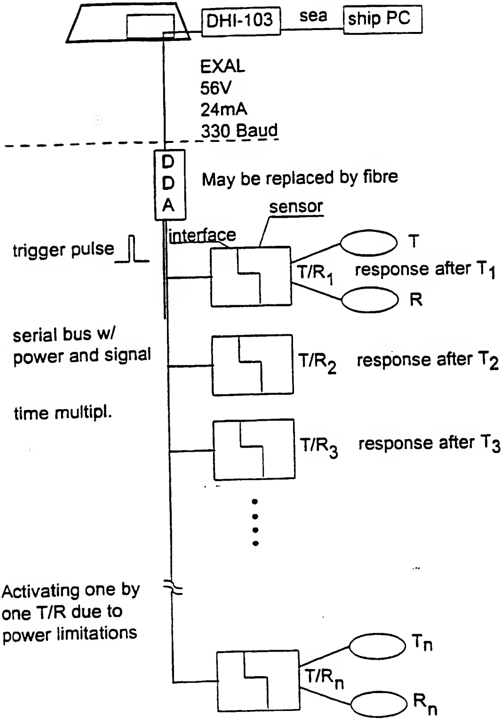
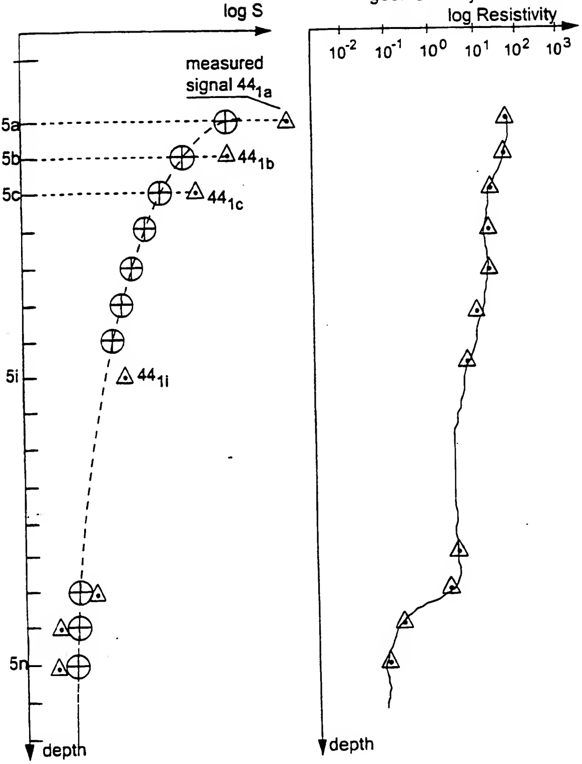

DHI-103
sea
ship PC
EXAL
56V
24mA
330 Baud
D
D
A
May be replaced by fibre
sensor
interface
trigger pulse
T
T/R1
response after T1
R
serial bus w/
power and signal
T/R2
response after T2
time multipl.
T/R3
response after T3
Activating one by
one T/R due to
power limitations
Tn
T/Rn
Rn

Fig. 7


log S
measured
signal 44_{1a}
5a
5b
44_{1b}
5c
44_{1c}
5i
44_{1i}
5n
depth
geometrically corrected
log Resistivity
10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3}
depth

9/12

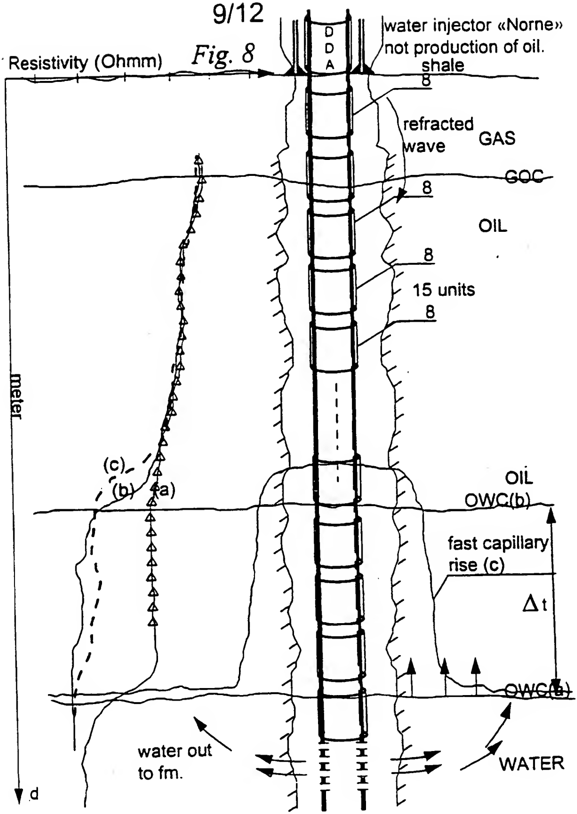

Resistivity (Ohmm)
D
D
A
water injector «Norne»
not production of oil.
shale
8
refracted
wave
GAS
GOC
8
OIL
8
15 units
8
meter
(c)
(b)
(a)
OIL
OWC(b)
fast capillary
rise (c)
Δt
OWC(a)
water out
to fm.
WATER
d

Fig. 8

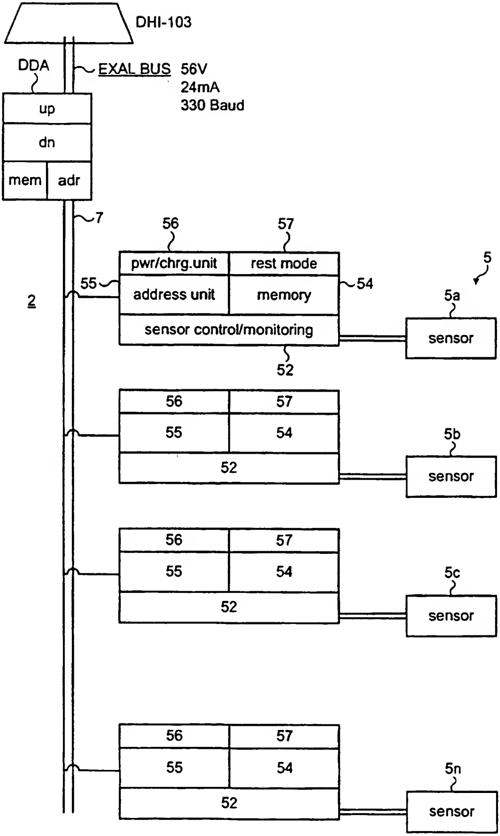
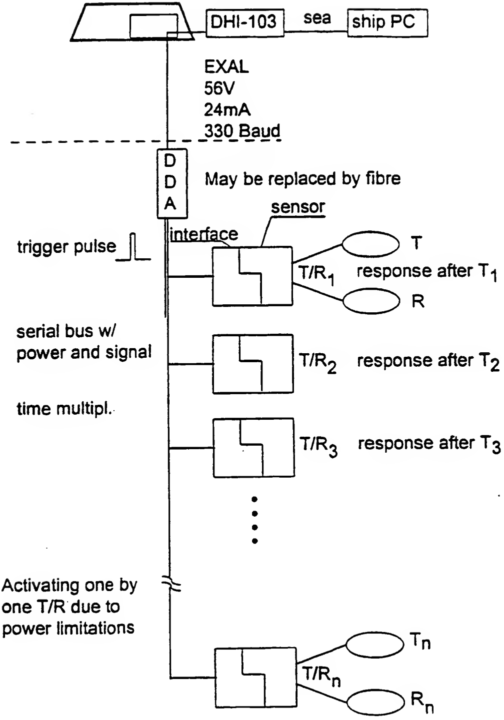

DHI-103
DDA
EXAL BUS
56V
24mA
330 Baud
up
dn
mem
adr
7
2
56
57
pwr/chrg.unit
rest mode
55
address unit
memory
54
sensor control/monitoring
52
5
5a
sensor
56
57
55
54
52
5b
sensor
56
57
55
54
52
5c
sensor
56
57
55
54
52
5n
sensor

FIG. 9

Fig. 9


DHI-103
sea
ship PC
EXAL
56V
24mA
330 Baud
D
D
A
May be replaced by fibre
sensor
interface
trigger pulse
T
T/R1
response after T1
R
serial bus w/
power and signal
T/R2
response after T2
time multipl.
T/R3
response after T3
Activating one by
one T/R due to
power limitations
Tn
T/Rn
Rn

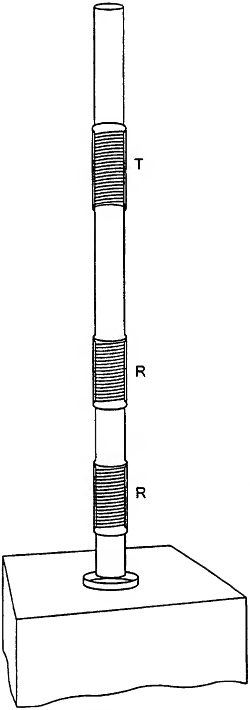


FIG. 10a

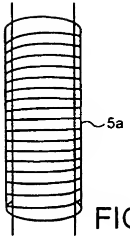


FIG. 10b

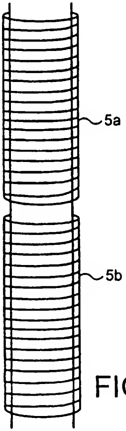


FIG. 10c

2355538

DEVICE AND METHOD FOR MEASUREMENT OF RESISTIVITY OUTSIDE OF A WELLPIPE.

Technical area of the invention.

This invention concerns an invention to measure resistivity in the geological formations surrounding a well in a petroleum reservoir. More particularly a measuring device is described, consisting of a transmitter antenna and a series of receiver antennas placed outside the lining pipe in an injection well or a production well.

Statement of problem.

During injection of water through an injection well in a petroleum reservoir it may be very useful with monitoring of the state of the reservoir. Of particular importance is to perform monitoring of the so-called oil/water contact (OWC) being the boundary surface between the usually overlying oil and the underlying water in the permeable rocks constituting the reservoir, e.g. sandstone or limestone. If water under large pressure is injected below OWC this may result in pressure increase in the oil- and gas reservoir above OWC, and result in increased outflow of oil and gas from production wells being in hydraulic communication with the injection well. A device and a method according to the invention will be used both in injection wells and production wells in order to measure and perform monitoring of the electrical properties in the reservoir to indicate, among other things, the position of the oil/water contact and its movement. It is very difficult to perform measurements of the resistivity in the geological formations if one has to measure through the wall of a metallic lining (casing) pipe, an injection pipe or production tubing. For observation of the oil/water contact's level changes it is therefore highly uncertain to perform such observations through the wall of the wellpipe. Further, in order to care for the flow capacity, it is not convenient to arrange measuring devices inside a wellpipe during normal operation of the well.

Below will be given a simplified summary of some of the factors which affect the propagation of electromagnetic

waves in a rock. According to the invention there will be emitted, from the transmitter antenna, electromagnetic waves in the form of continuous, sweep or pulsed waves. These pulses are refracted in the rock strata relatively shallowly in the geological formation so that a part of the energy is picked up in the receiver antennas.

The attenuation or reduction of the energy of the electromagnetic signal happens essentially due to three main factors:

I: geometrical, approximately spherical dispersion,

II: electrical properties (resistivity and dielectric) and

III: backscattering (homogenous backscattering from reflecting geological electrically conductive more or less homogenous horizons, and occasional backscattering due to reflecting mineral particles).

AboutI: The geometrical, approximately spherical dispersion follows approximately $1/r^3$ with r being the distance between transmitter and receiver.

AboutII: The electrical properties is the resistivity and the varying dielectric (called the "dielectric constant".) The relative dielectric constant varies from 6 for 20%-porous oil saturated quartz sand to ca. 13 for water saturated 20%-porous quartz sand. The resistivity in the rocks also determines the attenuation of the electromagnetic pulses. In Fig. 5 the attenuation in dB/m is displayed as function of frequencies between 1 and 16 MHz, for resistivities between 5 Ωm and 30 Ωm. The resistivity of oil sand in the reservoir may be between 20 and 200 Ωm. The resistivity of rocks containing formation water, below the oil/water contact (OWC) is between 0.5 and 5 Ωm. Thus the electromagnetic pulses will be attenuated much more while the transmitter- or receiver antennas are situated below the oil/water contact OWC than while the receiver antennas find themselves surrounded by oil-saturated sandstone.

AboutIII: Backscattering or reflection occurs from geological or fluid surfaces being homogenously continuous at an extent of comparable with the wavelength of the electromagnetic waves. For the actual rocks this is for

wavelengths between 2 and 8 MHz crudely estimated from 10 to 2 metres. In this invention's connection this reflection a pure loss of signal.

AboutIII: Occasional backscattering happens especially by point reflection from electrically conductive mineral grains in the rocks, e.g. pyrite, haematite and magnetite.

Examples of the known art.

An apparatus for measurement of formation resistivity through casing pipes is given in US. patent 5 680 049. The US. patent has electrodes being pressed against the casing pipe from a logging sonde by means of hydraulics. The logging thus occurs through an electrically conducting casing pipe which will mask the much lower conductivity (i.e. higher resistivity) in the rocks outside the casing pipe.

One method for more direct measurement of formation resistivity and reservoir monitoring outside a casing pipe is given in US. patent 5 642 051. Electrodes are cemented fixed in the well outside the casing pipe in hydraulically isolated zones of the reservoir. A current is sent between an electrode in the ground outside the reservoir and the electrodes in the well. In column 2 in US. patent 5 642 051 is described that an electrical isolation is required on the outside of the casing pipe. In this way one may regard the method for less actual for most purposes, as one must take into account that smaller and larger rifts in the isolation around the casing pipe must be expected during the installment, especially for petroleum wells below the seabed. It is also very difficult to imagine communication with electrodes in a production or injection well by means of electrically conducting in the seabed, as the wellstring from a floating platform will be impossible to isolate electrically.

An electromagnetic pulse transmitter is described in US. patent 4 849 699. In the actual US. patent the pulser is designed into a logging tool which by definition is arranged to be displaced through a borehole or a lined well.

Another pulse induction logging tool is described in US. patent 4 481 472.

According to one aspect of the invention, there is provided an apparatus for measurement and monitoring of resistivity in a petroleum reservoir in a geological formation with an injection-, observation- or production well comprising an electrically conductive metallic wellpipe, characterised by

a) an electrical energy source;

b) at least one inductive transmitter antenna for electromagnetic waves, arranged for fixed arrangement in the well, outside both the wellstream and the wellpipe's outer metallic surface;

c) at least one sensor series comprising a number of n inductive, magnetostrictive or electrostrictive resistivity sensors, with n>=1, arranged with a mutual separation lengthways of the borehole, and arranged for receiving the electromagnetic waves and generation of measurement signals, and arranged for fixed arrangement in the well, by the petroleum reservoir and outside of the wellpipe's outer metallic surface;

d) a signal conductor for the measurement signals; and

e) devices arranged to give a volumetric measure of the resistivities in the petroleum reservoir.

The invention also extends to a method for measurement of resistivity in a petroleum reservoir in a geological formation with an observation- or production well comprising an electrically conductive metallic wellpipe, characterized by the following steps: conducting a number of two to m measuring series each comprising the following steps (i) – (v):

i) emission of electromagnetic waves from an inductive transmitter antenna arranged for fixed arrangement in the well, outside both the wellstream and the wellpipe's outer metallic surface, to a part of the petroleum reservoir,

ii) reception of electromagnetic waves by a sensor series comprising of n points using inductive, magnetostrictive or electrostrictive resistivity sensors being fixedly arranged lengthways of the borehole outside the electrically conductive metallic wellpipe and outside of the wellstream;

iii) generation of measurement signals representing the electromagnetic waves sensed

by the resistivity sensors;

iv) registration of signal representations of the measurement signals, the index corresponding to the number in the measuring series, and

v) storage of the signal representations;

forming of a difference between the second or later signal representations and the preceding signal representations;

interpreting the difference with regard to changes in the position of liquid surfaces' level in the reservoir.

Additional features of the invention are given in the dependent claims.

Description of the drawings.

Below a description of the invention will be given, with reference to the following drawing figures, with:

Fig. 1 illustrating in principle an injection well at an oilfield at sea. The injection well is attached to a well frame or wellhead and has a pipe connection with a production vessel at the surface.

Fig. 2a displays schematically an embodiment of the invention with a transmitter antenna and a sensor series in a petroleum well, with the sensor series possibly consisting of electric coils or antennas.

Fig. 2b displays schematically an alternative embodiment of the invention with a transmitter antenna and a sensor series in a petroleum well, with the sensor series possibly consisting of optical sensors arranged to sense electromagnetic signals.

Fig. 3 displays an addressed control unit on a so-called communication bus for use in a preferred embodiment of the invention. Each control unit may have connected one transmitter antenna and at least one sensor.

Fig. 4 shows a first preferred embodiment of the invention, a module of a wellpipe comprising a transmitter antenna and two receiver antennas in the form of coils around the wellpipe.

Fig. 5 is a diagram of attenuation of electromagnetic waves in a conductive medium, e.g. a rock, with resistivities in the range between 30 Ωm and 5 Ωm, by a relative dielectric constant of 6, for frequencies between 1 MHz and 16 MHz.

Fig. 6 shows an illustration of a possible embodiment according to the invention, of the energy supply and the signal transport from the resistivity sensors to the surface.

Fig. 7 displays an illustrated imagined log of resistivity measured according to the invention.

Fig. 8 displays an illustration of an imagined injection well in a geological formation with a schist barrier above a gas-, oil- and water-bearing formation, with

a wellpipe pumping water into the water-bearing part of the formation. A series of modules of an embodiment according to the invention is arranged along the wellpipe. Imagined logs of resistivity is displayed by the graphs (a) early in the injection phase and (b) later in the injection phase, and a graph (c) indicating remaining oil removal.

Fig. 9 displays an illustration of the main features in a communication device for application with the invention.

Figs. 10a, 10b and 10c show a laboratory model of a preferred modular embodiment according to the invention. The laboratory model is constructed in scale 1:3.

Detailed description.

Fig. 1 and Figs. 2a and 2b display an injection-, observation- or production well 2. The well may comprise an electrically conductive metallic wellpipe 3, e.g. an injection- or production tubing 3 and possibly comprising a perforated or permeable liner pipe 6. These electrically conductive wellpipes may constitute the mechanical basis for the transmitter antenna 4 and a sensor series 5 according to the invention. A metallic pipe outside the transmitter antenna 4 or sensors 5 will attenuate the signals to a high degree. Essential in this connection is that if a liner or casing pipe 6 is arranged outside the production tubing, the transmitter antennas 4 and the resistivity sensors (5a, 5b, ..., 5n) constituting the sensor series 5 being arranged and fixed also outside of this outer metallic surface in the well. In a preferred embodiment of the invention the antennas are arranged such that no electrically disturbing fluid flow pass between the antenna and the borehole wall. In a preferred embodiment of the invention the transmitter antennas 4 and the sensor series 5 is cemented fixed together with the wellpipe 3,6. The invention is in the preferred embodiment especially arranged for being installed in an injection well, but also possible to being installed in production- or observation wells. Water may be injected in a perforated zone of the wellpipe into a water-bearing part of a reservoir 1 in a geological formation 9. The resistivity in the water-bearing zone typically is 0.5 to 5 Ωm such as indicated in Fig. 1. The resistivity in the oil-

bearing part of the reservoir 1 typically is between 20 and 200 Ωm, with little change by the transition to the gas-bearing zone.

General embodiment.

An electronic energy source or accumulator 10' is arranged preferably near the at least one inductive transmitter antenna 4 being arranged for emission of electromagnetic waves 40. The transmitter antenna 4 is fixedly arranged in the well 2, outside the wellpipe's 3,6 outer metallic surface, and in a preferred embodiment generally such that no electrically disturbing fluid flow may pass between the antenna and the borehole wall. At least one sensor series 5 comprising n inductive resistivity sensors (5a, 5b, ..., 5n) arranged for reception of the electromagnetic waves 40 and generation of measurement signals 42, are fixedly arranged in the well 2, 2', by the petroleum reservoir 1 and outside the wellpipe's 3, 6 outer metallic surface. The present invention gives in a preferred embodiment a volumetrically measured resistivity, not by means of electrodes arranged for measurement of resistivity by direct electrical contact with the formation. The fixed arrangement in the well 2 of the antennas is preferably performed by fixation cementing by means of cement. Fixation by means of hardening mass as glue etc. may be imagined. A signal conductor 7 for the measurement signals 42 leads to a registration unit 70 for signal representations 44 of the signals 42, which further represent the electromagnetic waves 40 sensed by the resistivity sensors (5a, 5b, ..., 5n).

By each resistivity sensor may be connected an addressable control unit 52 displayed in Fig. 3 and Fig. 9. Resistivity sensors (5a, 5b, ..., 5n) may be connected in pairs to each their control units 52, possibly together with one transmitter antenna 4. The control unit 52 may comprise at least one memory 54, and address unit 55, and energy/charging unit 56 and a rest mode unit 57, and may be connected via the signal conductor 7 with e.g. the registration unit 70 which may be situated down by the reservoir, by the wellhead at the seabed, on a platform or

at a ship having signal communication with the wellhead and further down to the sensor series 5. In one embodiment each resistivity sensors (5a, 5b, ..., 5n) may be connected to each their control unit 52, in another embodiment all the resistivity sensor may be connected to one single control unit 52. Due to effect- and signal capacity limitations between the particular components and the registration unit 70, and further between the registration unit and the surface, each control unit may be set into or out of rest mode by a command to the rest mode unit 57. In such manner each sensor may be controlled to give measurement signals upon command.

Modular embodiment.

In one preferred embodiment one inductive transmitter antenna 4 and preferably one sensor series 5 comprising n=2 inductive resistivity sensors (5a, 5b) are arranged in a module 8 arranged for being combined in selected combinations of modules 8 and other wellpipe parts together constituting a wellpipe 3. Because one usually know the position of the reservoir very well in injection- and production wells, modules 8 are entered into the well completion string 3 before the entire string is installed in the well. The signal conductor 7 and the control units 52 including the registration unit 70 may be arranged in ready milled tracks on the wellpipe 3 and its modules 8, or such tracks may be prefabricated on the wellpipe 3 and its modules 8. When the wellpipe 3 is arranged in the well 2 it is fixedly cemented to the wall of the borehole in the ordinary way.

Electrical embodiment.

The sensor series with the resistivity sensors (5a, 5b, ..., 5n) consists in a preferred embodiment preferably of electrical coil antennas, preferably pairs of resistivity sensors (5a, 5b) with n=2.

The inductive transmitter antenna 4 for electromagnetic waves 40 is in a preferred embodiment arranged for transmission of coherent continuous electromagnetic waves. A preferred frequency range for the electromagnetic waves is

from 1 to 20 MHz, but other frequency ranges are not excluded. In an additionally preferred embodiment of the invention the inductive transmitter antenna 4 is arranged for emission of electromagnetic waves in the frequency range 2-8 MHz. In alternative embodiments the emission of the signals may take place by means of sweep signals inside the preferred frequency range. An additional alternative embodiment of the invention may be arranged to emit electromagnetic pulses, e.g. by means of a pulse transmitter such as disclosed in US-pat. 4 849 699. In the mentioned US. patent the pulse transmitter is designed into a logging tool being by definition arranged to be displaced through a borehole or a lined well.

A ceramic isolator 43 is arranged between the metallic wellpipe 3 and the inductive transmitter antenna 4. This is displayed in Fig.4, with the module 8 having milling-cut cut-outs in the wellpipe 3 in a cylindrical volume under the transmitter antenna 4. A corresponding ceramic isolator 45 is arranged between the metallic wellpipe 3 and each of the resistivity sensors (5a,5b,...,5n). In order to protect and isolate the antennas and the sensors, an isolating sleeve 46 is arranged outside on the inductive transmitter antenna 4 and the resistivity sensors (5a, 5b, ..., 5n). This isolating sleeve 46 does not necessarily need to be continuous between the transmitter antenna 4 and the resistivity sensors (5a,5b, ..., 5n) internally. A hydraulically balancing cavity 48, filled preferrably with silicone oil, is arranged between the metallic wellpipe 3 with the inductive transmitter antenna 4 and the resistivity sensors (5a,5b,...,5n), and the electrically isolating sleeve 46. This cavity's liquid distributes pressure and reduces mechanical shear forces so that it protects the module's electrical components.

On the modules 8 are found in a preferred embodiment of the invention elastic centralizers 49 arranged near each inductive transmitter antenna or sensor series 5, preferably in at least one end of each module 8.

Energy supply and signal transport.

The energy supply may happen from the outside of the well, but in a preferred embodiment of the invention is applied a local energy source or accumulator 10' and an energy supply conductor 10 by the inductive transmitter antenna 4. The energy source or accumulator 10 may be

charged via energy supply conductors (not shown) from the surface. In a preferred embodiment of the invention, illustrated in Fig. 9, all signal transmission and energy supply between e.g. a well frame at the seabed or generally on the surface and the well via a so-called EXAL-bus having a highest signal speed of 300 Baud and up to 56 V voltage and 24 mA maximum current. In the well frame may be arranged a communication card of the type DHI-103 using this EXAL-bus. An alternative to the communication card DHI-103 is a corresponding one named DHI-107 having five times higher effect.

Alternative embodiment.

In an alternative embodiment of the invention illustrated in Fig. 2b, the transmitter antenna 4 may consist of a high-effect pulse emitting capacitive coil, preferably wound around the wellpipe 3 in a way corresponding to the description in MPI's US. patent 4 849 699 for a logging tool. This capacitive coil is arranged for slow charging with the capacity permitted by the energy supply and signal conductors, and arranged for time-controlled discharge via a spark gap. Such a transmitter antenna 4 will have a very large effect and will give an electromagnetic pulse reaching far down into the geological formation.

In an alternative embodiment there may be arranged an optical fibre 7 constituting a signal conductor 7 for communication between the resistivity sensors (5a, 5b, ..., 5n) and a registration unit 70 for signals 42 which represent the electromagnetic waves 40 sensed by the resistivity sensors (5a, 5b, ..., 5n). Each resistivity sensor (5a, 5b, ..., 5n) may be constituted by a magnetic coating 52 on Bragg-gratings 50 arranged to couple changes of the inducing electromagnetic field to changes in the optical Bragg-grating 50. Each Bragg-grating constituting a part of each resistivity sensor (5a, 5b, ..., 5n) on the optical cable has each its discrete internal grating separation different from the other resistivity sensors (5a, 5b, ..., 5n). Mechanical vibrations will be induced on the Bragg-grating so that the internal grating separation will

vibrate about the initial separation. In this way a broad-spectered optical pulse from e.g. registration unit 70. Each resistivity sensor (5a, 5b, ..., 5n) then will "respond" on the optical pulse by reflecting the locally sensed electromagnetic frequency and amplitude and phase as signals 42 modulated in each their frequency band on the broad-spectered optical pulse. The signals 42 represent the electromagnetic waves 40 sensed by the resistivity sensors (5a, 5b, ..., 5n). This is possible because the broad-spectered optical pulse has very rapidly vibrating frequency in the nanometre range, while the electromagnetic pulses as mentioned above reside between 2 to 10 metres. The signals 44 may be transformed e.g. to digital signal representations 44. Thus it is in the alternative embodiment of the invention possible to perform several readings by many resistivity sensors (5a, 5b, ..., 5n) simultaneously via one single optical cable. This optical cable may alternatively lead the entire way from the sensors 5 to the surface.

Signal processing.

The transmitter antenna will radiate energy in all directions out into the formation. Depending on the wavelength of the emitted signal there will be one corresponding critical angle leading to refraction of the electromagnetic wavelength so that the energy propagation takes place in the geological formation 9 near the wall of the borehole. This refracted wave will radiate out and back again from the borehole wall and be sensed by the sensors (5a, 5b, ..., 5n). Reflections along the refracted path will be a pure loss in this measurement process. This refracted wave will be the first arrival to the sensors, and in a preferred embodiment this first arrival constitutes the electromagnetic radiation being most suitable for the purpose for the invention. Reflections from more remotely situated parts of the formation will arrive later and will thus be disregarded. Further, reflections will, in most actual considerations, be several dB lower than the refracted wave, so that the reflected waves will have little effect on the part of the measurement signal which according to the invention will be transformed to registered signals

which should represent the resistivity.

Method of resistivity measurement.

A preferred embodiment of the invention consists basically of a method for measurement of resistivity in a petroleum reservoir 1 in a geological formation 9 with an injection-, observation- or production well 2 by means of a device given in claim 1. The method comprises the following steps:

i) emission of electromagnetic waves 40 from the inductive transmitter antenna 4 to preferably the upper part of the petroleum reservoir 1,
ii) reception of electromagnetic waves 40 by a sensor series 5 of n inductive resistivity sensors (5a, 5b, ..., 5n) arranged by the petroleum reservoir 1;
iii) generation of signals 42 representing the electromagnetic waves 40 sensed by the resistivity sensors (5a, 5b, ..., 5n); and
iv) registration of signal representations 44 of the signals 42.

Primarily the refracted part of the electromagnetic waves 40 will be applied for generating signals 42, further being transformed to signal representations 44. The resistivity may be calculated on the basis of the amplitude and the phase of the received waves 40. The signal representations 44 will according to a preferred embodiment of the invention be drafted as a log of resistivity in the reservoir. In order to trace the development in the reservoir during time, the operation may utilize a method comprising the following steps:

a) a first performance of the steps (i-iv) according to the method described above;
b) storage of the first signal representations 44_1;
c) a second performance of the steps (i-iv) according to the method mentioned above;
d) storage of the second signal representations 44_2;
e) formation of a difference 46 between the second signal representations 44_2 and the first signal representations 44_1;

f) interpretation of the difference 46 with regard to changes in liquid surfaces, preferably those of an oil/water contact's (OWC), level in the reservoir 1.

With one transmitter antenna 4 and a long series of resistivity sensors (5a, 5b, ..., 5n) corrections should be made for geometrical, approximately spherical or cylindrical dispersion of the electromagnetic wave before the log is drafted on the basis of the measurements or the signal representations, such as illustrated in Fig. 7. By interpretation of the difference 46 it is however in one basic embodiment only the relative changes of the signal between the signal representations 44_1, 44_2, ..., 44_t as a development through time, measured at each particular of the sensors (5a, 5b, ..., 5n) being necessary to monitor the movements of the oil/water contact. With a series of modules 8 arranged along the wellpipe 3 it will preferably be equal separation between each pair of transmitter antenna and resistivity sensor S_i in the sensor series 5. Thus an observation log may be drafted on the basis of the pair by pair measurement of resistivity without need to make geometrical correction of the measurements.

Figs. 10a, 10b and 10c illustrate a laboratory model of a preferred modular embodiment according to the invention. The laboratory model is designed in scale 1:3.

The above mentioned embodiments are to be considered as non-limiting examples of possible embodiments of the invention. The invention is only limited by the attached patent claims.

Claims

1. Apparatus for measurement and monitoring of resistivity in a petroleum reservoir (1) in a geological formation (9) with an injection-, observation- or production well (2,2') comprising an electrically conductive metallic wellpipe (3,6), characterised by:
   a) an electrical energy source (10');
   b) at least one inductive transmitter antenna (4) for electromagnetic waves (40), arranged for fixed arrangement in the well (2), outside both the wellstream and the wellpipe's (3,6) outer metallic surface;
   c) at least one sensor series (5) comprising a number of *n* inductive magnetostrictive or electrostrictive resistivity sensors (5a, 5b, ..., 5n), with n>=1, arranged with a mutual separation lengthways of the borehole, and arranged for receiving the electromagnetic waves (40) and generation of measurement signals (42), and arranged for fixed arrangement in the well (2,2'), by the petroleum reservoir (1) and outside the wellpipe's (3, 6) outer metallic surface;
   d) a signal conductor (7) for the measurement signals (42); and
   e) devices arranged to give a volumetric measure of the resistivities in the petroleum reservoir based on the measurement signals (42).

2. Apparatus according to claim 1, characterised in that at least one inductive transmitter antenna (4) and at least one sensor series (5) comprising *n* inductive resistivity sensors, magnetostrictive or electrostrictive resistivity sensors, (5a, 5b, ... 5n) are arranged in a module (8) arranged to be combined in selected combination of modules (8) and other wellpipe parts together constituting a wellpipe (3).

3. Apparatus according to claim 1 or 2,
characterized in
that the sensor series (5) with the resistivity sensors (5a, 5b, ..., 5n) consists of electrical coil antennas .

4. Apparatus according to claim 1 or 2,
characterized in
that the inductive transmitter antenna (4) for electromagnetic waves (40) is arranged for emission of coherent continuous electromagnetic waves.

5. Apparatus according to claim 1, 2, 3 or 4,
characterized in
that the inductive transmitter antenna (4) is arranged for emission of electromagnetic waves in the frequency range 1-20 MHz.

6. Apparatus according to claim 5,
characterized in
that the inductive transmitter antenna (4) is arranged for emission of electromagnetic waves in the frequency range 2-8 MHz.

7. Apparatus according to claim 5,
characterized in
that the inductive transmitter antenna (4) is arranged for emission of electromagnetic waves at stepwise different frequencies.

8. Apparatus according to claim 1, 2 or 3,
characterized in
that the inductive transmitter antenna (4) is arranged for emission of electromagnetic waves by sweep with continuously varying frequency in the frequency range 1-20 MHz.

9. Apparatus according to claim 1, 2, or 3,
characterized by

a ceramic isolator (44) arranged between the metallic wellpipe (3) and the inductive transmitter antenna (4).

10. Apparatus according to claim 1, 2, or 3,
c h a r a c t e r i z e d b y
a ceramic isolator (44) arranged between the metallic wellpipe (3) and the resistivity sensors (5a, 5b, ..., 5n).

11. Apparatus according to one of the preceding claims,
c h a r a c t e r i z e d b y
an electrically isolating sleeve (46) arranged outside of the inductive transmitter antenna (4), and the inductive resistivity sensors, the magnetostrictive or electrostrictive resistivity sensors, (5a, 5b, ..., 5n).

12. Apparatus according to claim 11,
c h a r a c t e r i z e d b y
a hydraulically balancing cavity (48) arranged between the metallic wellpipe (3) with the inductive transmitter antenna (4) and the inductive resistivity sensors, the magnetostrictive or electrostrictive resistivity sensors, (5a, 5b, ..., 5n), and the electrically isolating sleeve (46).

13. Apparatus according to claim 3,
c h a r a c t e r i z e d b y
elastic centralizers (49) arranged near each inductive transmitter antenna (4) or sensor series (5).

14. Apparatus according to claim 1,
c h a r a c t e r i z e d b y
an addressable control unit (52) connected to at least every sensor series (5), with the control unit (52) at least comprising a memory (54), and address unit (55), an energy/charging unit (56), and a rest mode unit (57), and connected via at least one signal conductor (7) with a registration unit (70) for signal representations (44) of the signals (42) further representing the electromagnetic

waves (40) sensed by the resistivity sensors (5a, 5b, ..., 5n).

15. Apparatus according to claim 14,
c h a r a c t e r i z e d b y
an inductive transmitter antenna (4) connected to each addressable control unit (52).

16. Apparatus according to claim 1,
c h a r a c t e r i z e d b y
a locally arranged energy source (10') and an energy supply conductor (10) arranged by the inductive transmitter antenna (4).

17. Apparatus according to claim 16,
c h a r a c t e r i z e d i n
that the energy supply conductor (10) and the inductive transmitter antenna (4) is arranged for rapid electromagnetic pulse discharge with high effect.

18. Apparatus according to claim 16,
c h a r a c t e r i z e d b y
an energy supply conductor (11) from a surface installation (100) to the local energy source (10').

19. Apparatus according to claim 1,
c h a r a c t e r i z e d i n
that the inductive resistivity sensors, or the magnetostrictive or electrostrictive resistivity sensors, (5a, 5b, ..., 5n) are arranged for generation of measurement signals based on the first arrivals of the electromagnetic waves (40).

20. Apparatus according to claim 1,
c h a r a c t e r i z e d i n
that the inductive transmitter antenna (4) consists of a high-effect pulse emitting capacitive coil.

21. Apparatus according to claim 1,

c h a r a c t e r i z e d b y
an optical fibre (7) constituting a signal conductor (7) for communication between the resistivity sensors, the magnetostrictive or electrostrictive resistivity sensors, (5a, 5b, ..., 5n) and a registration unit (70) for signal (42) representing the electromagnetic waves (40) sensed by the resistivity sensors, the magnetostrictive or electrostrictive resistivity sensors, (5a, 5b, ..., 5n).

22. Apparatus according to claim 1 or 21,
c h a r a c t e r i z e d b y
optical resistivity sensors, optical magnetostrictive or electrostrictive resistivity sensors comprising a magnetic coating (52) on a Bragg-grating (50) arranged to transform changes in an inducing magnetic- or electric field, e.g. the electromagnetic waves (40) to physical changes in the Bragg-grating (50).

23. Method for measurement of resistivity in a petroleum reservoir (1) in a geological formation (9) with an observation- or production well (2,2') comprising an electrically conductive metallic wellpipe (3,6), characterized by the following steps:

conducting a number of two to m measuring series (a, b, .., m) each comprising the following steps (i) – (v):

i) emission of electromagnetic waves (40)from an inductive transmitter antenna (4) arranged for fixed arrangement in the well (2), outside both the wellstream and the wellpipe's (3,6) outer metallic surface, to a part of the petroleum reservoir (1),

ii) reception of electromagnetic waves (40) by a sensor series (5) comprising of n points using inductive, magnetostrictive or electrostrictive resistivity sensors (5a, 5b, ..., 5n) being fixedly arranged lengthways of the borehole outside the electrically conductive metallic wellpipe (3,6) and outside of the wellstream;

iii) generation of measurement signals (42) representing the electromagnetic waves (40) sensed

by the resistivity sensors (5a, 5b, ..., 5n);

iv) registration of signal representations (44_1, 44_2,..,44_m) of the measurement signals (42), the index corresponding to the number in the measuring series, and

v) storage of the signal representations (44_1, 44_2,..,44_m);

forming of a difference (46) between the second or later signal representations (44_2,..,44_m) and the preceding signal representations (44_1,..,44_{m-1});

interpreting the difference (46) with regard to changes in the position of liquid surfaces' level in the reservoir (1).

24. Method according to claim 23, characterized by post-processing to calculate the volumetric resistivity on the basis of the measurement signals (42) or the signal representations (44).